INVESTIGATION OF HEAT FLOW CHARACTERISTIC IN AN INDUSTRIL OVEN USING ANSYS

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SUPERVISOR'S DECLARATION

I have checked this report and the report can now be submitted to JK-PSM to be delivered back to supervisor and to the second examiner.

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal-Fluid).

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DEDICATION

This is for my ibu and ayah. The reason why am I still holding on what I should hold. The ultimate weapon for me to stand up eight times when I fall hard seven times.

Without them I am nothing. I love you.

ABSTRACT

Temperature uniformity is the most important factor to design an oven. There's various design of an oven in the industry. However, most design having the same problem which is the uniformity of the temperature distribution inside the oven. Temperature distribution depends on the hot air circulated inside the oven cavity. The geometry design of the oven also the main concern along the heating coil design and position. Circulated hot air inside the cavity drive by a fan. A fan will circulate the hot air. The position of the device also play an important role. The material used for each wall inside the oven also affecting the temperature distribution. A numerical investigation using Computational Fluid Dynamic(CFD) technique will help in the initial process to design an oven. This numerical will give an early predicted of what will happen inside the oven. This simulation also shows the behavior of the air inside the oven. The result can be compared with different model in order to have better cooking result. The simulation for both oven shows different result. Forced convection have better cooking condition than natural convection.

ABSTRAK

Untuk merekabentuk sesebuah ketuhar, keseragaman suhu merupakan faktor yang sangat penting. Pelbagai jenis rekabentuk ketuhar yang terdapat dipasaran. Walaubagaimanapun, kebanyakan rekabentuk menhadapi masalah yang sama iaitu keseragaman suhu di dalam ketuhar. Rekebentuk geometri sesebuah ketuhar merupakan faktor penting yang di ambil kira selain rekabentuk rod pemanas dan juga kedudukan rod pemanas diletakkan. Pergerakan udara panas didalam ketuhar di bantu dengan kehadiran kipas. Kipas akan menggerakkan udara panas diseluruh kawasan didalam ketuhar. Selain daripada itu, kedudukan peranti diletakakn juga boleh menjadi faktor penting. Bahan yang digunakan untuk setiap dinding didalam ketuhar juga boleh diambil kira. Kajian berangka menggunakan teknik Komputer Dinamik Bendalir akan memudahkan proses awal untuk merekabentuk sesebuah ketuhar. Kajian ini akan memberi ramalan awal tentang keadaan di dalam ketuhar. Simulasi ini juga membantu untuk mengkaji pergerakan udara didalam ketuhar. Hasil daripada simulasi yang dijalankan boleh membantu untuk membandingkan rekebentuk yang akan menghasikan kaedah memasak yang terbaik. Simulasi daripada kedua-dua ketuhar menunjukkan keputusan yang berbeza. Ketuhar daya perolakan menunjukkan keadaan memasak yang lebih bagus daripada ketuhar perolakan semula jadi.

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CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBEREVATIONS

CFD	Computational Fluid Dynamics
Re	Reynolds number
Ram	Modified Rayleigh number
Nu	Nusselt number
DTRM	Discrete transfer
S2S	Surface-to-surface
DO	Discrete Ordinate

LIST OF SYMBOL

μ	Dynamic viscosity
v	Kinematic viscosity
U	Velocity
ρ	Density
k	Turbulent kinetic energy
cp	Specific heat
P	Pressure
T	Temperature
ε	Turbulent dissipation
g	Gravitational acceleration
β	Coefficient of thermal expansion
ϕ	Porosity
Q	Heat flow
d_m	Material thickness
S_{ij}	Strain-rate tensor

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Non-uniform heat distribution is still one of the main concern that been taking as a main factor to improve the best baking condition for different type of heating system. This concern has been observed using different oven. In commercial usage, there a lot of type of oven. Commonly the type of oven was differentiating by the type of heating mode. The main mechanism of heat transfer is forced convection. In any type of ovens, heat will always have been forced using different type of heating mode. An oven usually has three types of heating mode, classic, fan and grilling. Thus, in this analysis there's only two types of oven will be used to compare with each other which is conventional oven and convection oven that usually been used at home.

Conventional ovens use radiant heat that been surrounding from the top and/or bottom surfaces to heat the oven chamber. By way of definition radiating heat is basically heating energy transmitted by electromagnetic waves in contrast to heat transmitted by conduction or convection. The result tends to produce hot and cold spots in the oven chamber which can often lead to uneven cooking results. For commercial cooking applications, this method of transferring heat can limit both cooking results and menu options by way of achieving an even cooking result.

Convection ovens deals with the problems of hot and cold spots and uneven like cooking result by using a fan to circulate air and keep the temperature steadier. When hot air is blowing onto food, as opposed to merely surrounding it, the food tends to cook more quickly. However, there's scientific explanation for this is that moving air speeds up the rate of heat transference that naturally occurs when air of two different temperatures converge. In short explanation, convection oven is an oven that using a fan that forced hot air which is circulated around the oven chamber and acting as a catalyst for faster heat transference and a more even cooking temperature.

In many cases, non-uniform heat distribution come from uneven heat transfer through each part of the chamber of the oven. Uneven heat transfer occurred due to poor temperature distribution and flow field in the ovens chamber. Due to this reason, the baking of cookies will not be same since some part of the cookies will burned caused by the temperature different in the oven chamber. This temperature different will be analyze using lumped system analysis.

Other than that, the cause of this concern maybe coming from the position and the design of heating of the heating coils of conventional ovens while the position of fan and also the design and position of heating coils will give different result of heat distribution in the oven chamber.

1.2 PROBLEM STATEMENT

Conventional oven was designed with the heating coils placed on top and bottom of the oven chamber with different design of heating coil. While the convection oven designed with different position of fan that will circulate the hot air that been heated by different design of heating coils that been placed either on top or bottom of the oven chamber. In this concern, non-uniform heat distribution appears only when the oven is used to bake cookies dough. However, when the ovens used to bake other type of food such as breadits show uniform heat distribution for both ovens.

Figure 1.1 : Conventional Oven

Figure 1.2 : Convection Oven

1.3 OBJECTIVE

The objectives of this project are as follows:

1. To investigate the flow of heat transfer in conventional and convection ovens.
2. To analyse the flow of heat transfer in conventional and convection ovens.
3. To compare the temperature distribution and velocity in convectional and convection ovens.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. Only heating mode classic will be analyzed of both ovens that will gave a comparison which oven is better for cookies baking.
2. Conventional oven will be analyzed with heating coil placed on top and bottom of the oven.
3. Convection oven will be analyzed with a fan place only at the back side of the oven and heating coil placed of top of the oven.

CHAPTER 2

Literature Review

2.1 Mechanism of Heat Transfer

Heat is a form of energy that can be transferred from one system to another system. There are three different ways for heat to be transferred which is: conduction, convection and radiation (A. Cengel, 2015). A temperature distinction is required for these methods of heat transferred to happen, and the heat dependably exchanges from areas of high temperature to lower temperature. The amount of heat transferred during the three process is denoted by Q while the heat transferred rate is denoted by $\dot{Q}$ which is define as heat transfer "per unit time". The heat transfer rate has the unit J/s which is equivalent to W(watt).

If the rate of heat transfer is available, the total amount of heat transfer Q during the time interval can be find from

$$Q = \int_0^{\Delta t} \dot{Q} \, dT \tag{2.1}$$

Provided that the variation of with respect to time is known. If the is constant, the equation above will be reduced to

$$Q = \dot{Q}\,\Delta t \tag{2.2}$$

2.1.1 Conduction

Conduction is the transfer of heat as a result of interactions between different particles (A. Cengel, 2015). Conduction can occur in solids, fluids and gases. In gases and fluids, conduction caused by collisions and diffusion of molecules during their random motion of movements. In solids, it is caused by vibrations of molecules in a lattice and the energy transport of free electrons. Steady one dimensional heat conduction is defined as

$$\dot{Q} = -kA\frac{dt}{dx} \tag{2.3}$$

which is also known as Fourier's law. Here *A* is the heat transfer surface area, which is always normal to the direction of heat transfer, and *k* is the thermal conductivity of the given material.

2.1.2 Convection

Convective heat transfer takes place in fluids in the presence of fluid motion (A.Cengel, 2015). Convective heat transfer is divided into natural and forced convection. In forced convection, the fluid motion is initiated externally, e.g. by a fan or a pump, while in natural convection it is caused by density differences in the fluid due to temperature gradients. Convective heat transfer from a solid surface to the surrounding fluid is defined as

$$\dot{Q} = hA(T_s - T_\infty) \tag{2.4}$$

which is known as Newton's law of cooling. Here h is the convection heat transfer coefficient, A is the heat transfer surface area, T_s is the temperature of the surface and $T\infty$ is the temperature of the fluid sufficiently far away from the surface.

2.1.3 Radiation

Radiation is a process where energy is emitted by matter in the form of electromagnetic waves (A. Cengel, 2015). Radiation does not, unlike conduction and convection, require a medium in order to transfer energy, it works just as well in vacuum. The relevant type of radiation for heat transfer studies is thermal radiation, which is emitted by all bodies at a temperature over absolute zero. The net radiative heat transfer is calculated as

$$\dot{Q} = \varepsilon \sigma A (T_S^4 - T_{Surr}^4) \tag{2.5}$$

where ε, A and T_s is the emissivity, surface area and absolute temperature, respectively, of a body and T_{surr} is the absolute temperature of the surrounding surface. The Stefan-Boltzmann constant σ, is equal to 5.67 × 10−8W ($m^2 \cdot K^4$).

2.2 Natural Convection oven

Heat that is transferred by natural convection is accompanied by radiation of comparable magnitude except for low emissivity surface. For an oven, natural convection relay on the temperature distinction within the hot air in the oven to the baking material. Heat that is supplied by the heating coil is not generated by any external sources (pump, fan, suction device) but the differences of the density between the hot air and the baking material due to temperature gradient. To have a uniform distribution of temperature the heat supplied from electric heaters or heating coils must be well designed and to determine the quality of the device the temperature field must be as uniform as possible. (Jacek, 2013).

Not only convection heat transfer occurs, radiation heat transfer also one of the factor that been study to optimize the distribution of temperature and velocity. The study about natural convection with or without presence. With presence of radiation, the temperature ratio of the heat transfer between both ways decrease slightly, for aspect ratio increase from unity and will increase drastically as the aspect ratio decrease from unity. While without presence of radiation, the ratio increased by increasing the absolute temperature (Abdulmaged, 2013).

Figure 2.1 : Natural Convection Oven (http://www.alamy.com)

2.3 Forced Convection Oven

Forced convection oven worked by the heat is transferred from the heating element via conduction, convection and radiation with the existed forced air by the external force device in the oven chamber (Sakin, 2008; Martin, 1997). Using a fan or jet impingement hot air is forced to circulate in the chamber. Uniformity of the temperature and velocity across the oven chamber is important to ensure that heat is equally transferred in the oven chamber. These two factors will result to the quality of the baking product. To maintain the uniformity of these factors, high air pressure is created in the plenum that provide the banks of the nozzles (Khatir, 2011).

Figure 2.2 : Forced Convection Oven (http://ovenreviewshq.com)

2.4 Governing Equation

The following equations are used in order to mathematically describe fluid flow in oven cavity.

2.4.1 Continuity equation

This is the three dimensional and unsteady continuity equation for a compressible fluid. The first term describes the rate of change in time of the density and the second term describes the net flow of mass out of the element boundaries.

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho U_j}{\partial x_j} = 0 \tag{2.6}$$

2.4.2 Momentum Equation

This is the momentum equation, or Navier Stokes equation, written in tensor notation. The momentum equation is obtained by applying Newton's second law to a fluid particle.

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \rho}{\partial x_i} + \frac{1}{\rho}\frac{\partial}{\partial} + g_i \tag{2.7}$$

2.4.3 Energy Equation

The energy equation for incompressible flow with constant C_p reads:

$$\rho \frac{du}{dt} = -p\frac{\partial U_i}{\partial x_i} + \Phi + \frac{\partial}{\partial x_i}\left(k\frac{\partial T}{\partial x_i}\right) \tag{2.8}$$

where Φ is defined as

$$2\mu S_{ij} S_{ij} - \frac{2}{3}\mu S_{ii} S_{kk} \tag{2.9}$$

and S_{ij} is the strain-rate tensor

$$S_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) \tag{2.10}$$

2.5 Dimensionless Number

The relevant dimensionless numbers that will be observed in the flow assumption in the oven are described below.

2.5.1 Modified Rayleigh number

The modified Rayleigh number, Ra_m, usually used in flow situations involving natural convection in porous media. It can be represented as a measure of the driving forces for natural convection, and is defined as

$$Ra_m = \frac{\rho c_{pg} \beta d_m K \Delta T}{v k_m} \tag{2.11}$$

2.5.2 Nusselt Number

The Nusselt number is the ratio between heat flux where convection is existed and heat flux without convection for the same situation. A Nusselt number represents heat transfer by pure conduction, while a Nusselt number larger than one means that convection has started. The larger the Nusselt number is, the more dominant convection is:

$$Nu = \frac{q_{with\ convec\ tion}}{q_{without\ \ convection}} \tag{2.12}$$